

## Description

Method for routing of data packets and routing apparatus

5 The present invention relates to a method for routing of data packets as well as a respective routing apparatus. In particular, the present invention relates to a method for routing of data packets according to the IPv6 protocol ("Internet Protocol Version 6") and a respective routing  
10 apparatus.

As one of the essential components of an internet data transmission system, an IP router ("Internet Protocol") makes a forwarding decision for an input data packet, i.e. it  
15 checks a destination address identifier carried in the packet header and directs it to the next output port or output link through which the data packet should be sent. For example, depending on the destination address identifier of the input data packet, the IP router can direct the data packet to a  
20 Next Hop router or an Egress<sup>TM</sup> port for transmission over a respective output link. In a computer network, the NHRP protocol ("Next Hop Resolution Protocol") is a protocol which can be used so that a computer sending data to another computer can learn the most direct route to the receiving  
25 computer. An Egress<sup>TM</sup> port is a new type of port used in modern IP routers.

In the following, the routing of data is briefly explained with reference to Figure 7 which shows the schematic  
30 construction of an IP router according to the prior art.

The IP router shown in Figure 7 comprises an input block 1 which receives a plurality of input data packets over N input links or input ports IN1-INN. The input block 1 serves as an  
35 input queue and outputs the received data packets in a "First In First Out" (FIFO) manner. A header extracting block 2 is provided which extracts the packet header from the respective

data packet to be transmitted so as to obtain the destination address identifier which is included in the packet header. In addition, the data packet is transferred to an output block 6 which serves as a switch. A routing table 4 stores all  
5 possible or available forwarding addresses and the respective output link/port numbers of the router. That is to say the routing table comprises a plurality of entries, each entry corresponding to a respective forwarding address to which a data packet can be forwarded by the IP router. The routing  
10 table 4 is generated and updated by a block 5 using routing protocols. In Figure 7, the routing updates are indicated with reference sign UPD. A routing unit 3 receives the destination address identifier extracted by the header  
15 extracting block 2 and uses this destination address identifier as a key for searching for a match in the routing table 4, i.e. the routing unit 3 compares the destination address identifier with every entry corresponding to a respective forwarding address information stored in the routing table 4. If the routing unit 3 finds a correspondence  
20 between the destination address identifier and one of the forwarding addresses stored in the routing table 4, the respective output link/port number is transferred to the switch 6, and the switch 6 switches the data packet to a respective one of a plurality of M output links/output ports  
25 OUT1-OUTM.

Hence, as long as the routing unit 3 finds a correspondence between the destination address identifier extracted by the header extracting block 2 and at least one of the entries  
30 stored in the routing table 4, the respective data packet can be switched to one of the output links OUT1-OUTM. If, however, there is no match for the destination address identifier in the routing table 4, the switch 6 cannot switch the respective data packet to one of the output links, and  
35 the data packet cannot be forwarded to its destination.

It is obvious that the cost associated with an IP router of the type shown in Figure 7 and its performance depend very much on the size of the routing table 4. The routing table 4 consumes silicon area and the look-up procedure consumes time as well as power, especially if the routing table 4 is large.

This problem in particular becomes more and more serious with the fast expansion of internet. The newly introduced IPv6 protocol provides address identifiers comprising 128 bits. Theoretically, for an  $n$ -bit destination address identifier, the routing table 4 may have up to  $2^n$  entries. Hence, as regards the IPv6 protocol, there is a need for an enormous storing capacity for storing such a large routing table 4. Such a large table size, however, makes the look-up procedure even impractical. Therefore, routing table look-up is regarded as the major bottleneck in today's routers.

The most straightforward method for routing table look-up is to perform a linear searching, i.e. compare the destination address identifier of the input data packet with each entry of the routing table until a correspondence between the address identifier and one of the entries in the routing table is recognized. Although this approach is simple, it is hardly used in actual practice due to its poor performance.

To speed up the look-up procedure, various strategies have been used. The most important ones are the usage of a so-called contents-addressed memory (CAM), the search according to a tree-based data structure, and the usage of so-called hashing strategies. Each of these known strategies has its own advantages and disadvantages. However, all of them are based on a search in the original data domain of the destination address identifier. Thus, all of these strategies require a relatively complex search procedure and a relatively large routing table size.

Therefore, the object underlying the present invention is to provide a routing method for data packets as well as a respective routing apparatus which allow a smaller size of the routing table and, thus, enable a faster search for a correspondence between the respective destination address identifier and the entries stored in the routing table and decrease the costs associated with the routing table.

According to the present invention, this object is achieved by a routing method for data packets as defined in claim 1 and a routing apparatus for routing of data packets as defined in claim 12. The dependent claims define preferred and advantageous embodiments of the present invention.

The basic idea of the present invention is that the routing table look-up can be performed in a compressed domain, i.e., before performing the look-up operation for an input data packet, its destination address identifier is first compressed to remove redundancy. Then, the look-up operation is carried out with the compressed destination address identifier as the key with respect to the routing table, the entries of which having been also compressed in the same manner as the destination address identifier of the input data packet.

Therefore, the look-up operation can be performed with respect to a smaller routing table and, thus, the costs and power consumption associated with the respective router can be reduced, while the performance of the router can be improved.

The compression of the destination address identifier as well as the forwarding address information entries of the routing table is performed according to one and the same data compression algorithm. In particular, a so-called lossless data compression algorithm is used which eliminates redundancy in the data without sacrificing any information

content. There are several popular algorithms and variants of them which can be used for lossless compression. The most important examples are those of the Huffman, Arithmetic, and Lempel-Ziv (LZ) family.

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Since the compression efficiency depends on the data characteristics of the destination address identifiers which the router deals with, parameters of the respective compressor, e.g. the code table, should be assigned or  
10 adjusted according to these characteristics.

As regards the data compression algorithm, a data compression algorithm can be used which utilizes a code table which assigns a symbol of the address information to be compressed  
15 a respective code word. Each code word has preferably a length which is inversely proportional to the appearance probability of the respective symbol in a given address table, for example an IPv6 address table. As a matter of course, the appearance probability of the symbols at the  
20 router input may also be considered to improve the overall performance.

By applying the above-mentioned data compression algorithm, the redundancy of the appearance distribution of some symbols  
25 or bit combinations in the destination address identifier is taken into account. Therefore, a kind of a spatial redundancy can be removed. However, there can still be other kinds of redundancy, e.g. redundancy in the time domain if there is a similarity of the destination address identifier for  
30 successive data packets. In order to remove such a redundancy in the time domain as well, there is preferably a feedback from the routing unit to the compressor unit used for compressing the destination address identifier so as to eliminate such a time domain redundancy and consider the  
35 similarity of a plurality of destination address identifiers within a data packet sequence.

Although the present invention can preferably be used for the routing of IPv6 data packets, the present invention is not limited to this preferred field of application and, as a matter of course, can be used for all kinds of data packets.

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In the following, preferred embodiments of the present invention will be explained in more detail with reference to the enclosed drawings.

10 Figure 1 shows schematically an IP router according to a preferred embodiment of the present invention,

Figure 2 shows an implementation example for an address compressor, a routing unit and a routing table shown in

15 Figure 1, using a Huffman data compression algorithm,

Figure 3 shows an example for a code table for the address compressor shown in Figure 2,

20 Figure 4 shows an example for a hexadecimal address to be processed by the address compressor according to the code table shown in Figure 3,

Figure 5 shows a table illustrating the test results of a  
25 test concerning the compression ratio of different IPv6 address tables,

Figure 6 shows the dependence of the number of averaged bits and the number of entropy bits per byte in an IPv6 address,  
30 and

Figure 7 shows schematically an IP router according to the prior art.

35 In practice, much redundancy may be involved in the destination address identifier to be processed by an IP router. To explore how much redundancy may be involved in an

IP address, an experiment was carried out that tested, with various address tables, how many bits are really necessary to represent the information included in a quad, i.e. 4 bits, of an IPv6 address.

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In Figure 6, the result of the test is shown in dependence upon the IPv6 address table size. A graph (i) shows the result of the test if a respective 4bit-quad of an IPv6 address is compressed by using a Huffman encoder, i.e. graph (i) shows the number of averaged bits, which are obtained after the Huffman coding, depending on the address table size. In addition, a graph (ii) shows the number of entropy bits per quad depending on the address table size. That is to say graph (ii) shows the theoretical result, i.e. the number of bits which are really necessary to carry the information of the quad. From Figure 6 it can be seen that, instead of 4 bits, the necessary bit number varies between 1.5 and 2. As the address table size exceeds  $3 \times 10^6$ , the number of bits which are really necessary to carry the respective address information reaches a stable value of about 1.8. This means a compression potential of approximately (at least) 50%. It is to be noted that in this experiment only the redundancy of appearance distribution of some symbols (bit combinations) in an address identifier was taken into account. This corresponds to a kind of spatial redundancy. There can still be other kinds of redundancy, for example a redundancy in the time domain if there is a significant similarity of the address identifiers for some data packets which are to be processed one after the other.

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It is not easy for a general look-up method to consider all kinds of redundancy completely. The approach described in the following in detail, however, makes it possible to combine the routing table look-up technique with a data compression technique. While the former technique is associated with a searching operation in a compact address table, the latter technique deals with all possible kinds of redundancy. By

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combining the advantages of both techniques, an optimum solution for the routing table look-up problem can be achieved.

5 Figure 1 shows the structure of an IP router according to a preferred embodiment of the present invention. Those components which correspond to the components shown in Figure 7 and having already been described before are indicated with the same reference signs as in Figure 7. In order to avoid  
10 repetitions reference can be made to the description with respect to Figure 7.

The IP router of Figure 1 differs from that shown in Figure 7 in that the IP router works in a compressed address domain. A  
15 first address compressor 7 is arranged in the path between the header extracting block 2 and the routing unit 3. This address compressor 7 translates the destination address identifier provided by the header extracting block 2, which comprises 128 bits for an IPv6 destination address  
20 identifier, for example, into an in average shorter form using a data compression algorithm. The compressed destination address identifier is then forwarded to the routing unit 3 and used as the key for the look-up operation with respect to the routing table 4. In addition, an  
25 identical address compressor 8 is arranged in the path between the block 5 generating and updating the routing table 4 and the routing table 4. Hence, the address compressor 8 stores the forwarding address information in a compressed form in the routing table 4 using the same data compression  
30 algorithm as the address compressor 7. Thus, the routing table 4 is provided in a very compact form and, in particular, the routing table 4 is consistent with the compressed destination address identifier output by the address compressor 7 and used as the key for the look-up  
35 operation by the routing unit 3. The routing unit 3 may use conventional methods for searching for a correspondence between the compressed destination address identifier and one



of the compressed forwarding addresses stored in the routing table 4.

The data compression algorithm used by the address  
5 compressors 7, 8 is particularly a so-called lossless data  
compression algorithm. Such a lossless data compression  
algorithm eliminates redundancy in the respective data  
without sacrificing any information content. There are  
several popular algorithms and variants of them which could  
10 be used for such a lossless data compression. The most  
important examples are the data compression algorithms of the  
Huffman, Arithmetic, and Lempel-Ziv (LZ) family.

Since the compression efficiency depends on the data  
15 characteristics of the destination address identifiers that  
the router deals with, at least some of the parameters of the  
address compressors 7, 8, e.g. the code table used by the  
address compressor, should be assigned or adjusted according  
to or in dependence upon these data characteristics.  
20 Therefore, the IP router shown in Figure 1 comprises a  
compressor parameter block 9 which collects this information  
on the data characteristics of the respective destination  
address identifier from the header extracting block 2 and  
calculates the compression parameters for the data  
25 compression algorithm used by the address compressors 7  
and 8.

As already described above, the address compression effected  
by the address compressors 7, 8 takes into account the  
30 redundancy of the appearance distribution of some symbols  
(bit combinations) in the respective destination address  
identifier. However, there can be another kind of redundancy  
in terms of the similarity of the destination address  
identifiers of a plurality of successive data packets. In  
35 order to eliminate such a redundancy in the time domain as  
well, the IP router according to Figure 1 comprises a  
feedback connection from the routing unit 3 to the address

compressor 7 used for compressing the destination address identifiers. Such a feedback from the routing unit 3 to the address compressor 7 allows to take into account the similarity of the destination address identifiers within a data packet sequence. This can be done, for example, by determining the forwarding address for the switch 6 on the basis of a forwarding address having been determined before in case the new destination address identifier, for which the forwarding address is to be determined by the routing unit 3, is very similar to the respective preceding destination address identifier.

Figure 2 shows an implementation example for the address compressor 7, the routing unit 3, and the routing table 4 shown in Figure 1. In particular, this implementation example corresponds to an architecture for processing IPv6 data packets. Although Figure 2 shows a hardware diagram of the respective components, as a matter of course, the proposed architecture can be implemented with different hardware in software or in a combination of hardware and software as well.

The address compressor 7 shown in Figure 2 receives an extracted destination address identifier ADR from the header extracting block 2 shown in Figure 1. In the case of an IPv6 data packet, this destination address identifier ADR comprises 128 bits which are divided into 32 4bit-quads by a block 10. Each quad is then translated into a code word comprising several bits using for example a code table shown in Figure 3. This is done by a coding block 13.

The code table shown in Figure 3 comprises a first column (A) listing all possible hexadecimal values of a quad comprising 4 bits. In a second column (B), the respective binary code assigned to each quad value is depicted. In addition, in a column (C) the code length for each code word is depicted.

The 32 code words output by the coding block 13 are then combined by an address composing block 14 so as to obtain the compressed destination address which is then buffered in a first buffer 20 of the routing unit 3. In addition, there is a block 11 storing the respective code word length table corresponding to column (C) of Figure 3, and a block 12 sums up the code word lengths output by the block 11 for the respective address identifier ADR. The result is then buffered in a second buffer 15. Hence, the buffer 15 stores the sum of the length of the code words for the respective destination address identifier ADR, i.e. the length of the compressed address identifier, while the buffer 20 stores the combination of the code words assigned to the respective destination address identifier ADR, i.e. the compressed destination address identifier. The result stored in the buffer 15 is calculated by the block 12 on the basis of column (C) shown in Figure 3, while the result stored in the buffer 20 is determined by the block 14 on the basis of column (B) shown in Figure 3.

Figure 4 shows an example for a destination address identifier ADR to be compressed in accordance with the code table shown in Figure 3. According to the code table of Figure 3, this address is compressed to 56 bits. Each "F" value results in 1 bit of the compressed address, each "E" value results in 1 bit of the compressed address, each "D" value results in 3 bits of the compressed address, the "B" value results in 5 bits of the compressed address, the "7" value also results in 5 bits of the compressed address, the "4" value results in 6 bits of the compressed address, and the "3" value also results in 6 bits of the compressed address. Hence, the compressed address determined according to the code table shown in Figure 3 comprises  $22 \times 1 = 22$  bits for all "F" values,  $1 \times 6 = 6$  bits for the "4" value,  $1 \times 5 = 5$  bits for the "B" value,  $1 \times 6 = 6$  bits for the "3" value,  $1 \times 5 = 5$  bits for the "7" value,  $3 \times 1 = 3$  bits for all "E" values and  $3 \times 3 = 9$  bits for all "D" values of the input destination

address. Thus, the compressed address comprises 56 bits in total.

The code table shown in Figure 3 is generated by the  
5 compressor parameter block 9 shown in Figure 1 which outputs  
the compressor parameters CPAR used by the blocks 11, 13 of  
the address compressor 7 shown in Figure 2. In particular,  
the code table of Figure 3 corresponds to a code having been  
implemented by a Huffman encoder. In the present case, the  
10 Huffman encoder assigns to each symbol (quad) a code word  
that has a length which is inversely proportional to the  
appearance probability of the respective symbol in an IPv6  
address table comprising 872640 entries (13962240 bytes). The  
implementation of such a Huffman encoder, either in software  
15 or in hardware, can be found in many documents and  
publications dealing with data compression. Therefore, a  
detailed description of such a Huffman encoder or of the  
construction of the compressor parameter block 9, which is  
implemented with a Huffman encoder, is not considered  
20 necessary.

The routing table 4 shown in Figure 2 is composed of possible  
forwarding addresses that are compressed with the same  
compression parameters CPAR, i.e. the same code tables as  
25 those used by the address compressor 7. These compressed  
forwarding addresses are arranged in sub-tables according to  
their length. The compressed address length  $b_0-b_N$ , the number  
of entries  $n_0-n_N$ , and the base address  $a_0-a_N$  of each sub-table  
are stored in a leading table 27. The routing unit 3 works to  
30 find a match for the compressed input destination address in  
the compressed routing table 4. This is effected as follows:

A block 17 reads an entry of the leading table 27 and sends  
the address length  $b_i$  thereof to a length comparator 16. The  
35 length comparator 16 compares the length of the compressed  
input address as stored in the buffer 15 with each entry read  
out by the block 17. The length comparator 16 compares the

length of the compressed input address with each address length  $b_i$  stored in the leading table 27 so as to find the corresponding sub-table. If a match is found by the length comparator 16, a block 18 is reset, and thereafter the block 5 18 sends the base address  $a_i$  of the found sub-table to a block 24 and initializes a counter 23 to the number of entries  $n_i$  of the respective sub-table for the following address look-up operation.

10 Then, the routing unit 3 compares the compressed input address itself, as stored in the buffer 20, with the compressed address  $c_{j,i}$  stored in the sub-table as determined by the above-described search operation. A block 24 reads an entry from the respective sub-table 28 and sends the address 15  $c_{j,i}$  to an address comparator 21. This address comparator 21 compares the compressed input address stored in the buffer 20 with the compressed forwarding address provided by the block 24. With each comparison operation effected by the address comparator 21, an AND gate 22 decrements the counter 23.

20 Therefore, the comparison operation of the address comparator 21 is repeated until a correspondence is found between the compressed destination address and one of the compressed forwarding addresses stored in the sub-table 28, or until the counter 23 is decremented to zero. An lbit-latch 25 holds the 25 latest comparison results of the address comparator 21. If there is a correspondence between the compressed input destination address and one of the compressed forwarding addresses stored in the sub-table 28, the lbit-latch 25 generates a signal for a logic gate 26, which effects a logic 30 AND operation between the output signal of the lbit-latch 25 and an inverted output signal of the counter 23. This output signal of the counter 23 has a low level as long as the counter 23 has not reached the value zero. Hence, the output signal VALID of the logic gate 26 indicates whether the 35 output port number or output link number  $o_{j,i}$  currently processed by the block 24 is valid and can be used for the forwarding operation of the switch 6 (see Figure 1). It

should be noted that the index "i" indicates the number of the respective sub-table, while the index "j" indicates the number of the respective entry within a sub-table.

- 5 A further block 19 of the routing unit 3 effects a byte alignment operation of the coded or compressed input address, which is stored in the buffer 20, by zero padding of the remaining bits.
- 10 According to the implementation example shown in Figure 2, each destination address identifier ADR is divided up into 4bit-symbols. However, as a matter of course, the destination address identifier may also be divided up in a different manner. In addition, the code table shown in Figure 3 is
- 15 determined only by considering the appearance probability of the respective symbols (quads) in a given address table, in the present case in an IPv6 address table. However, the appearance probability of the symbols at the router input can also be considered in order to improve the performance of the
- 20 IP router. Finally, as already indicated above, the present invention is by no means limited to Huffman codes. Any lossless data compression algorithm can be used as a basis for the implementation of the address compressors 7, 8, the routing unit 3 and the routing table 4.
- 25 The model of using compressed destination address identifiers and compressed forwarding addresses was tested using a plurality of IPv6 address tables of various sizes. Figure 5 illustrates the test result. Column (A) indicates the number of the respective IPv6 address table, column (B) contains the number of entries of the respective IPv6 address table,
- 30 column (C) contains the original sizes (bytes) of the IPv6 address table, column (D) contains the compressed sizes (bytes) of the IPv6 address table, and column (E) indicates the compression ratio (%) which could be achieved. As can be
- 35 seen, the required size of the routing table can be reduced dramatically. This leads to an improved performance of the IP

router and helps to save memory and power for the look-up operation. The test result coincides with the theoretical analysis of Figure 6.